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## Uncertainty in Climate Models

Thomas M. Smith *et al.* ("how accurate are climate simulations?", Perspectives, 19 April, p. 483) suggest that today's climate models simulate the climate history of Earth over the past 150 years "within the observed uncertainty of the observations." In comparing model results with trends in sea surface temperature in several ocean basins, they estimate the uncertainty in model output arising from the inherent chaotic variability of the climate system from the spread of three separate simulations of a single climate model "forced with the same greenhouse gases and sulfate aerosols" but initiated with different conditions. They conclude that the variability in modeled temperature trends arising from the nonlinear dynamics of the climate system is small relative to the uncertainty in observations. However, as the model studies used only a single set of forcings, the conclusions neglect the major source of uncertainty in model simulations of temperature trends, that arising from uncertainty in the forcing.

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As emphasized in the recent reports of the Intergovernmental Panel on Climate Change (IPCC) (1) and the National Research Council (2), this uncertainty is substantial, a factor of severalfold, arising mainly as a consequence of uncertainty in the totality of aerosol forcings, not just that of sulfate. What is therefore required to estimate uncertainty in modeled temperature trends is a set of calculations for forcings that span the estimated uncertainty range. If this range of forcings were input into climate model calculations, the range of model results would greatly exceed that due to climate system chaos reported by Smith *et al.* The spread of modeled temperature trends would be even greater if a suite of modern climate models were used, because of the spread in climate sensitivity of these models. Such uncertainties preclude inference from the observed temperature trend either of the historical trend in forcing or of the sensitivity of the climate system. Thus, although the need for improving the observational climate record noted by Smith *et al.* should not be minimized, the need for improved knowledge of climate forcing must be viewed as far greater.

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### References

1. J. T. Houghton *et al.*, *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge Univ. Press, Cambridge, 2001).
2. National Research Council, *Climate Change Science: An Analysis of Some Key Questions. Committee on the Science of Climate Change*, R. J. Cicerone, chair (National Academy Press, Washington, DC, 2001).

### Response

The importance of accurately measuring climate forcings that cause climate variability and change is, indeed, critical to our ability to understand and predict climate. The IPCC (1) report indicates that the range of global temperature increase estimated by climate model projections is large (1.4° to 5.8°C), because of differences in climate model responses to changes in climate forcing as well as the future changes in the forcing, such as the growth of anthropogenic greenhouse gases and

aerosols. Clearly, we cannot ignore the importance of precisely monitoring the changing composition of the atmosphere, as well as other potential climate forcings, such as solar variability.

However, in our Perspective, we show that one set of GFDL model simulations forced with greenhouse gases and sulfate aerosol concentrations that are similar to those of several other simulations (1) is not deficient in simulating long-term trends in sea surface temperatures (SSTs). This is because of the significant uncertainties related to observed SSTs and the inherent chaos in the climate system. By far, the primary forcing of the late 19th century and the 20th century has been changes in the concentration of carbon dioxide, methane, and the halocarbons, which are known quite accurately (1). The time history of changes in other forcings, such as anthropogenic aerosols and greenhouse gases like ozone, is less certain. For natural forcings such as solar variability, there is substantial uncertainty, but this uncertainty is almost certainly much smaller than that for greenhouse gas forcing (2). If these additional uncertainties related to all these forcings were included in climate model simulations, they would surely have added to the model uncertainty somewhat. This further emphasizes one of our points: that existing models reproduce large-scale changes in observed SST as well as can be expected, but reductions in SST biases are also essential. Whether uncertainties related to credible scenarios of past forcing greatly exceed the uncertainties due to climate chaos, as Schwartz states, is speculative and remains to be shown, but it is clear that we must improve observations related to both climate state and climate forcings to better evaluate our models.

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1. J. T. Houghton *et al.*, *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge Univ. Press, Cambridge, 2001).
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Volume 296, Number 5576, Issue of 21 Jun 2002, pp. 2139-2140.

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